Empirical Assessment of Evapotranspiration (*ET*) using Turc method in Kulong Chhu basin, Bhutan.

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Abstract— *Evapotranspiration (ET) rate has not been determined in all the places within the country, Bhutan. Not all the places have complete information about the loss of water from the land surfaces (soil and vegetation) and water bodies. This results in less knowledge about the irrigation of the crop, precipitation and hydrologic cycle. The aim of this project is to estimate the daily ET of each elevation band for the year 2020 within the Kulong Chhu basin. The ET calculation is based on the TURC method (1961) that uses the least parameters under the humid condition. DEM of 30m resolution obtained from the USGS was used to extract and mask the area of interest. The study area DEM has been used to classify the elevation into different band based on equal interval. The daily mean temperature (T_{mean}) and relative humidity (RH) obtained from NCHM and solar radiations (R_G) from PADS have been interpolated within the study. These raster data (RH, T_{mean} and R_G) have been masked using each elevation band and calculated the average value for each band. Hence these average values of RH, T_{mean} and R_G were used to calculate the daily ET of each band. A graph of each elevation band versus its ET has been plotted to compare the ET for different elevation band. The annual ET in Kulong Chhu basin was estimated to be 395.633mm/year.*

Keywords—ET, Turc method, Elevation band, DEM

I. INTRODUCTION

Bhutan is highly vulnerable to the adverse impacts of climatic change [1] . The country has been facing some impacts of climate change such as crop loss to erratic rainfalls, windstorm, hailstorms, droughts and flash floods [2]. To facilitate such impacts, the knowledge of evapotranspiration is very important as the ET data is used to tackle the issues related to the water and the climate change. Evapotranspiration is the loss of water in the form of vapor from the water and land surface (evaporation) and from the living plants (transpiration) from the stomata opening during photosynthesis. ET plays a vital role in assessing so many problems related to scarce of water especially in arid and semiarid regions. The ET values are essential in hydrological modelling, drought assessment, agricultural irrigation management, in water balance and so on. Without ET values those assessments cannot be carried out so the assessment of ET is must, prior to such assessment.

To compute ET, FAO-PM method is the globally accepted standard method ensuring the most reliable results [3]. But in some places like Bhutan, some data were not available to perform PM method. In such cases empirical methods such as Turc, Hargreaves, Priestly-Taylor and so on are used which provide the results that are comparable to PM method. The area of Kulong Chhu basin is the study area where this project is determined to assess ET using Turc method (radiation-based method).

Among the several methods approached to find alternatives to PM method carried out in Northeast regions of India, Turc method gives results comparable with the P-M method and it was observed the best suitable option to P-M method[4]. In Bhutan, the empirical equation was used to compute *ET* and compared against *ET* value by the Penman Monteith method [3]. So, we can use empirical methods like Turc method to compute ET consisting parameters like relative humidity and temperature which are available from NCHM.

Evapotranspiration is a significant component taking part in the climate change and must know the variation of *ET* value in particular places. *ET* is important in hydrological modeling, drought assessment and water depletion from the ground. However, the value or the variation of *ET* in Trashi Yantse is not determined till now. In order to do further research based on water depletion and climatic conditions the value of ET is must. Therefore, the purpose of this project is to estimate the daily *ET* for the area of interest for the year 2020 using Turc method. It is very important to estimate the water requirements for agricultural and so the *ET*. Estimating *ET* and water scarce is important for irrigation monitoring and drought assessment [5]. Though the Turc equation gives unreliable result with adjusted equation and less parameter,the calibrated one gives reliable *ET* value as that of P-M method as well as better results [6].

The *ET* was determined by comparing P-M method, Turc method and Makkink method and Turc method gives the lowest ET_O value. However, in the case of limited data, Turc method is mostly used to calculate *ET* [7].

The compromise and grouping decision making method was used to rank 31 empirical ET_O model based on four statistical metrics and found that P-M method gives good result in estimation of ET_O. Nevertheless, Turc method also give similar result [8].

The model was established to predict evapotranspiration (*ET*) and water balance and test the linkage to vegetation and land cover using meteorological data. The calibrated Hargreaves (H) equation was used to compute *ET* and compared *ET* value against Penman Monteith method [3].

However to identify the suitable alternative to the FAO-56 Penman-Monteith equation to calculate reference ET_O from chosen temperature and radiation base models among the several methods approached, Turc method gives results comparable with the P-M method and it was observed the best suitable option to P-M method [4].

Using remotely sensed solar radiation evapotranspiration was estimated and methods used are the FAO P-M method and several empirical methods like Hargreaves, Turc and Priestly-Taylor method. At last, the results from those empirical methods were also compared with the P-M method and Turc method give the reliable result [9].

Monthly *ET* model was established using novel hybrid machine at Ranichauri (India) and at Dar El Beida (Algeria) station. The evaluation provides better estimates at both the station using Turc method [10].

[11] compared the evapotranspiration results from the rain-fed grass in central Serbia, using six empirical methods against Penman-Moneith method and reported Turc produce ultimate result. The result provides a reference tool that offers concrete guidance which method to select based on available data and consistence estimates of monthly evapotranspiration.

To estimate daily reference crop evapotranspiration model using different empirical model the result showed that PM method is efficient for humid climate while others overestimate and underestimate the ET_O whereas Turc method is alternative to P-M method as it requires scarce of data work best in the absence of P-M method [12].

To examine the accuracy of the classification, ground truth verification was carryout. ArcGIS was used to produce land use/cover and also remote sensing technique was used to examine data [13]. Monthly change in *ET* in Boston lake basin was influence by rainfall, temperature and vegetations. *ET* was impact by land use/cover type that is the daily *ET* was higher near the mountain area and lower at unused land [14].

According to Thomas, (2015) P-M method are the only reliable estimation of ET in mountain regions and temperature-based estimate such as Thornthwaite or Hargreaves are extremely not appropriate/reliable particularly in mountain regions whereas radiation based method best for this studied.

The reduced set P-M method and Hargreaves equation overestimate reference evapotranspiration while Turc equation neither overestimate nor underestimate. Moreover, Turc equation is recommended for estimating reference evapotranspiration in the absence of calibrated methods [16]

Different method was performed to predict the actual evapotranspiration of potato crop in semi-arid environment. The result show that P-M method over predict actual evapotranspiration. Whereas Turc, Priestly Taly, Makkink obtained more appropriate results for this particular area [17].

Three radiation-based method and temperature-based method was performed to estimate *ET* and to project future change against P-M method. From radiation-based method Makkinki method give best result. Although other method performed best but Turc method is easy to use as it requires three parameters to estimate *ET*. From temperature-based method Thornthwaite method was found best for projecting future change [18].

In order to determine relation between different reference evapotranspiration estimation method and standard P-M method, the equation is compared and calibrated against P-M method. It was found that Turc, Blaney Criddle FAO24 and Regression method gives the best result based upon all statistical criteria. Thus, these methods are reliable and recommended in the studied region. While other method after calibration though it gives satisfactory result but less reliable than other best method [19]..

The four models such as Makkink, Turc, Priestley Taylor and Hargreaves were used to estimate *ET* with limited data. In various climate. Turc model was considered best to estimate *ET* in cold humid. The Hargreaves model under warm humid and semi-arid climatic condition give best results vice versa. Makkink model perform worst in all climate except for cold humid condition. However, Turc and Hargreaves showed accurate *ET* value [20]. Due to lowest RMSD, Turc equation give most reliable *ET* value at humid condition [21].

Therefore, this project estimates the daily *ET* value using Turc's method with limited parameters such as solar radiation, temperature and relative humidity. The *ET* estimation is based on the categorized elevation band within the study area for the year 2020. The end result also derived a relation between estimated ET value and elevation band.

II. DATA AND METHODS

2.1 Study area

The eastern Dzongkhag, Trashi Yangtse is located in the sub-tropical and alpine forest consisting of rich natural resources and vegetation. The majority of the area is occupied by the Kulong Chu basin with a computed area of 1526km^2. The computed stream length of 82.5112km Kulong Chhu runs approximately from an elevation of 3691m to the river mouth of Drangme chhu. With the majority coverage of watershed by Kulong Chhu, its tributaries from different location aids in agricultural farming and other human activities. The annual average minimum and maximum rainfall for the year 2020 were approximately 453.614 mm and 1750.18 mm respectively. From the LULC chart, the area is covered by the maximum of forest followed by the shrubs/meadows. The agriculture land aids up to 1.57% of the total area with 2110.60 hectares of dry land and 949.30 hectares of wet land. The snow and glacier cover up to 12.47% of the total area. The extracted minimum elevation of the study area from the DEM varies from 818.03m to 5733.12m.

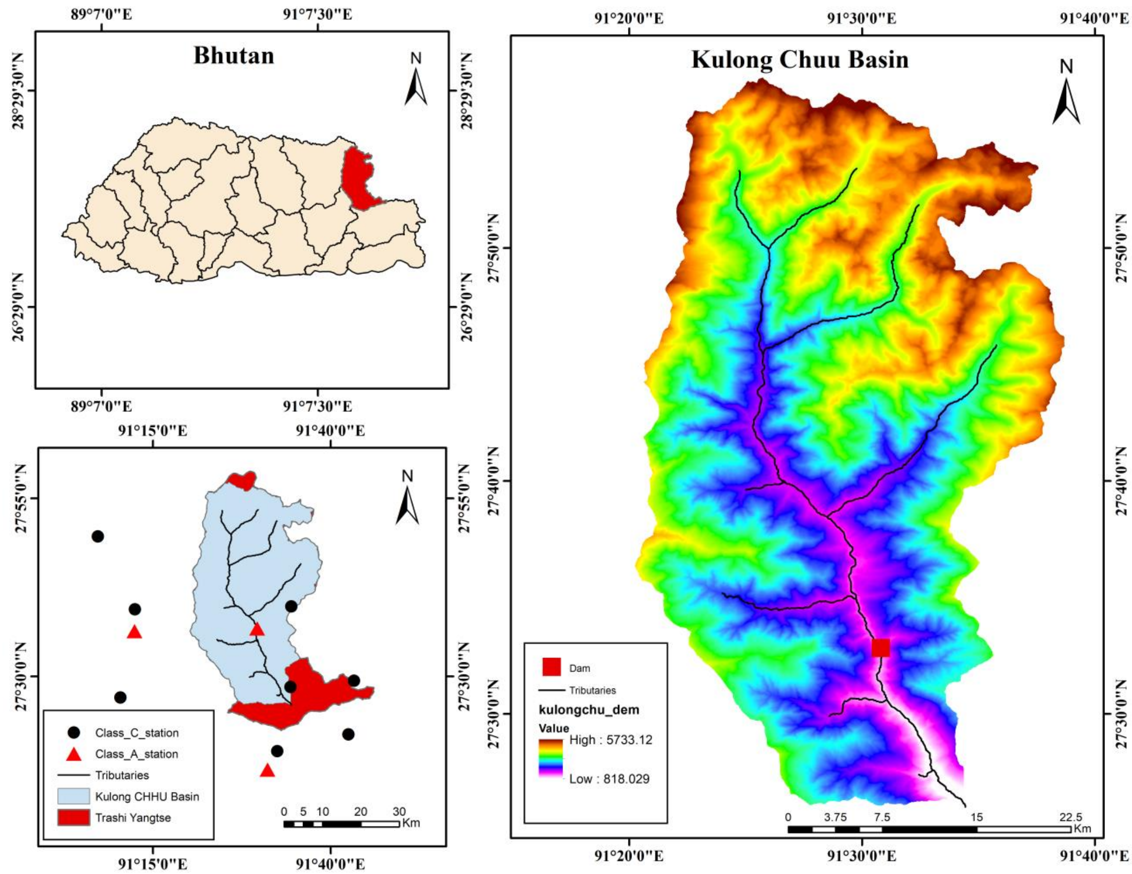


Figure 1 Kulong Chhu basin

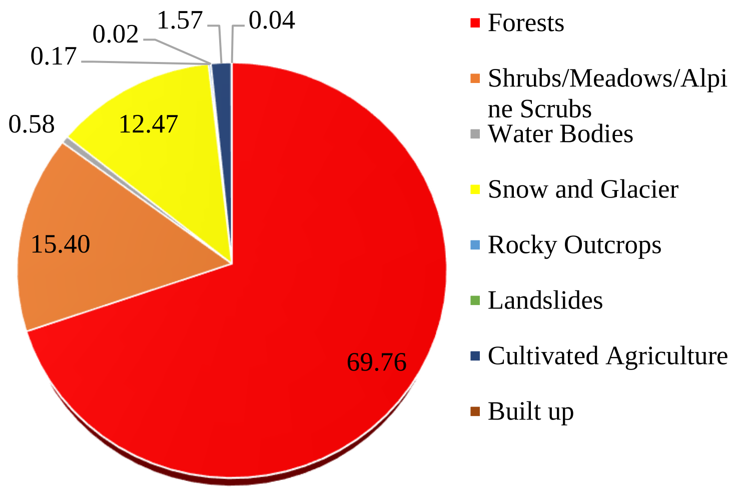


Figure 2 LULC chart of KUlong Chhu basin

2.2 Data availability

The data such as daily maximum and minimum temperature and relative humidity (RH) of 11 stations were obtained from National Center for Hydrology and Meteorology (NCHM). The minimum and maximum temperature was used to obtain the mean temperature (T_{mean}) for each station. Furthermore, the solar radiation data (R_G) was downloaded from the https://power.larc.nasa.gov/data-access-viewer/ which had 20 grid points with provided coordinates. The Digital Elevation Model (DEM) was downloaded from the https://earthexplorer.usgs.gov/. The resolution of the DEM downloaded from the United States Geological Survey (USGS) was 30m.The basin for the study area was delineated from the DEM using GIS. After obtaining the basin, the DEM for the study area was also extracted from the USGS DEM using the basin of study area.

2.3 Preparation of Elevation band

The objective of this study is to estimate the daily average *ET* from each elevation band; therefore, the DEM was categorized into five elevation band with an equal interval which is as shown in the *figure 3*. The minimum and maximum elevation of Kulong Chhu basin is from 818.04m and 5733m respectively. The main requirement was the shapefile of each band that can be used to clip the raster data of the *ET factors* (R_G, RH and Temp).

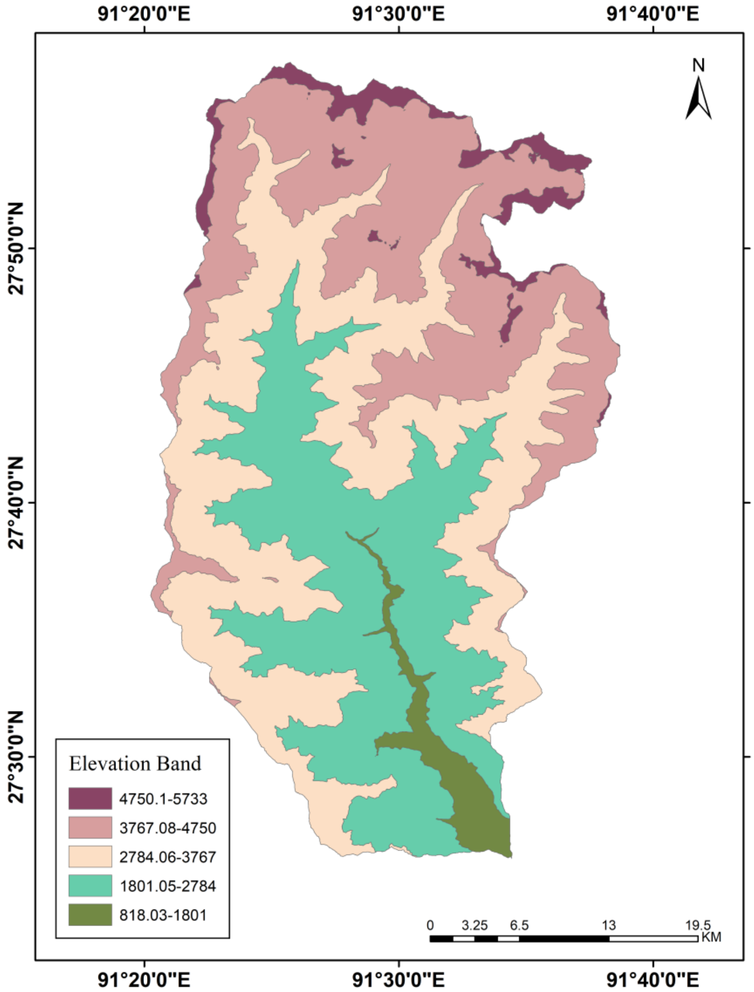


Figure 3 Elevation band

2.4 Preparation of raster data

Evapotranspiration depends on several factors such as solar radiation, air temperature and humidity. In this project, the daily *ET* rate of each elevation band was determined using the limited data such as solar radiation (R_G), mean temperature (T_{mean}) and relative humidity (RH). Using the 11 meteorological stations, the daily data for T_{mean} and RH were used to create a raster data for daily frequency for the year 2020. The Inverse Distance Weighted (IDW) technique was used for interpolating the data into raster data in GIS. Similarly, the daily R_G data was also interpolated to raster data for daily frequency for the year 2020. The raster data were masked using the shapefile of Kulong Chhu basin. Using the elevation bands, the raster data are clipped into different bands. The average value for all the parameters (R_G, RH and T_{mean}) from each clipped raster was computed. The same process was carried out for all the daily raster data for the year 2020.

2.5 Estimating ET using Turc Method

Turc method was adopted for the determination of *ET* for those places which had a limited climatic data. This method requires fewer data such as solar radiation, temperature and relative humidity.

$$ET = \alpha C(Rg + b)\left(\frac{Tm}{Tm+15}\right) \quad for\ RH < 50\% \qquad (1)$$

$$C = 1 + \left(\frac{50-\mathrm{RH}}{70}\right) \qquad (2)$$

$$ET = a(Rg + b) for\ RH \geq 50\% \qquad (3)$$

$$C=1 \qquad (4)$$

Where, *a* and *b* are empirical constants with $a = 0.31$ m^2MJ^{-1}, $b = 2.094$ $MJm^{-2}day^{-1}$, *ET* is in $mmday^{-1}$, *T* is in ^0C, R_G in MJ $m^{-2}day^{-1}$ and *RH* in %

The average value for each parameter (*RH*, T_{mean}, *and* R_G) was extracted from each elevation band at a daily frequency and subsequently was used to calculate the *ET* using *equation 1* and *equation 3*. The data was further aggregated into monthly and seasonal estimates.

III. Results

Evapotranspiration calculated by the Turc method gave an average of *ET* of 2.59mm/day for the entire elevations band, on average (Fig 4 and 5) and in the table 1. For daily *ET*, maximum *ET* 5.118 mm/day was observed in the highest elevation (4750.01-5733m) on the 26th August and minimum *ET* 0.385 mm/day on 31st August in the elevation (1801.05-2784m).

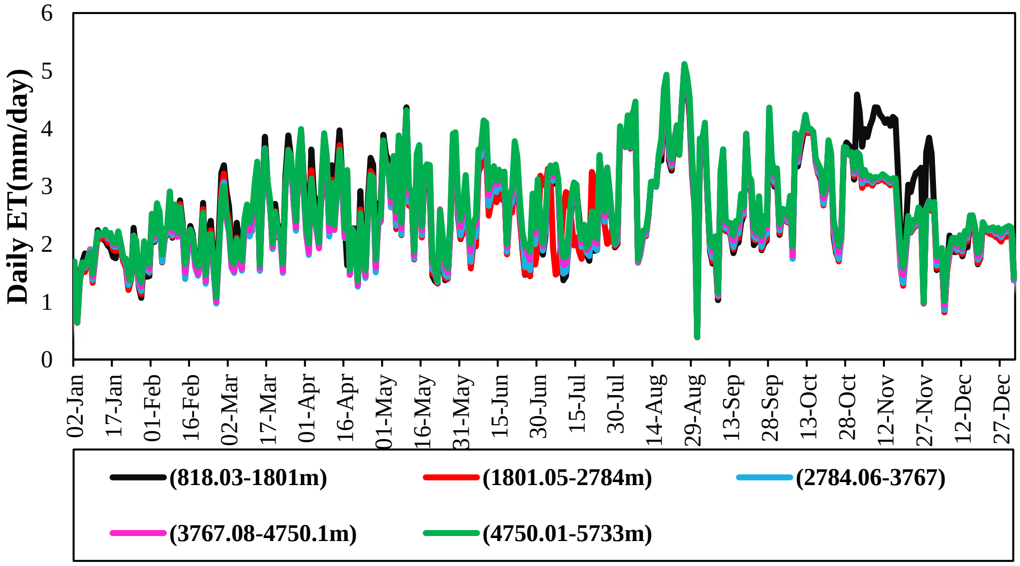
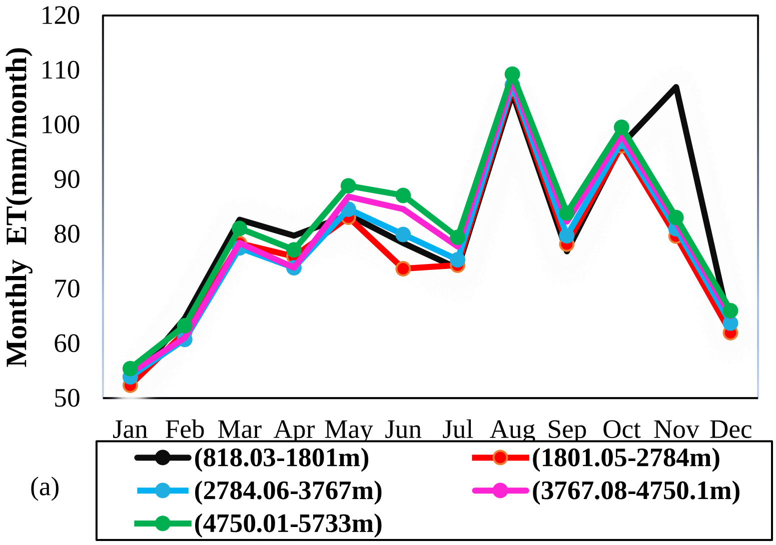


Figure 4 Daily ET

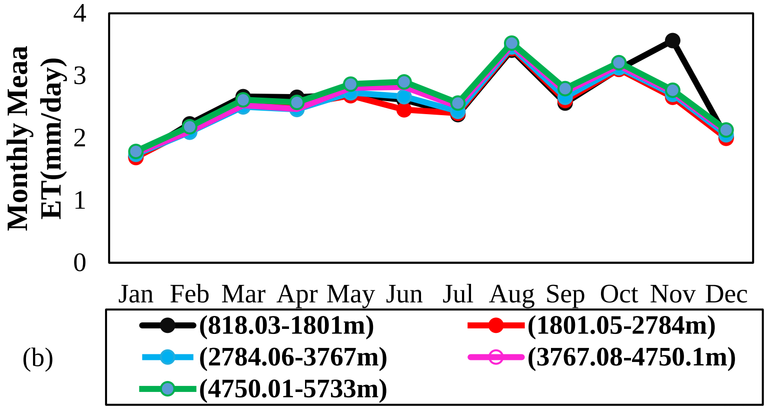
Regions with the highest elevations (4750.01-5733m) observed the highest *ET* in the month of August and the lowest in the month of January. Regions at the lowest elevation (818.03-1801m) at the month of November observed the highest *ET* and lowest in January. For the entire elevation band, the maximum *ET* was observed in the month of August due to high rate of solar radiation and temperature.

Table 1 Statistics of daily ET for each elevation band

Elevation(m)	Max	Min	SD	Mean
818.03-1801	5.076	0.386	0.858	2.633
1801.05-2784	5.047	0.385	0.803	2.520
2784.06-3767	5.079	0.387	0.807	2.554
3767.08-4750.1	5.093	0.386	0.801	2.603
4750.01-5733	5.118	0.387	0.793	2.661



(a)



(b)

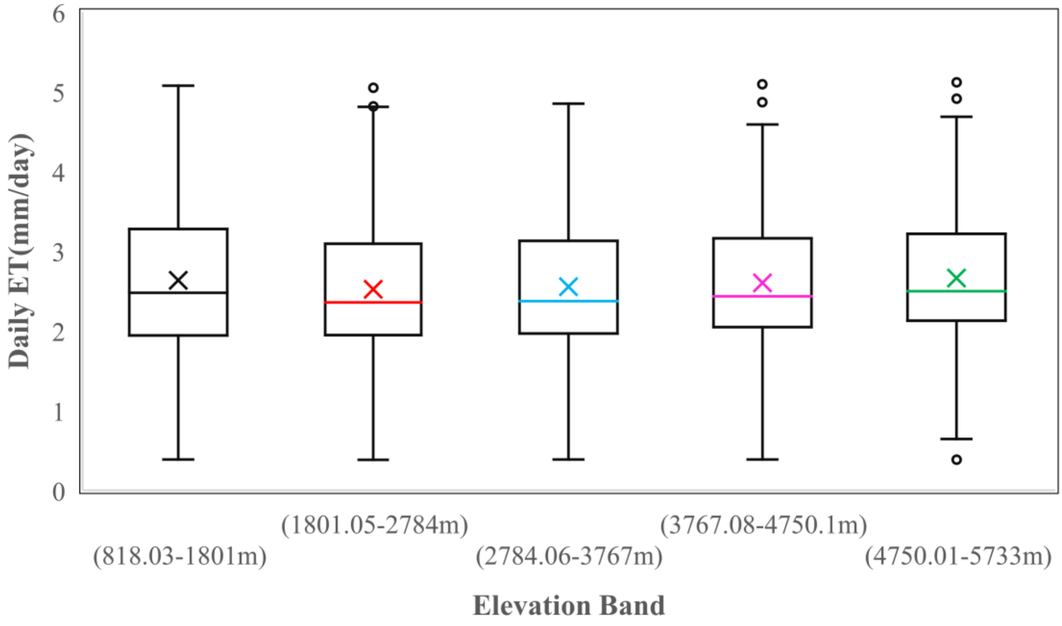
Figure 5 (a) Monthly ET (b) Monthly mean ET

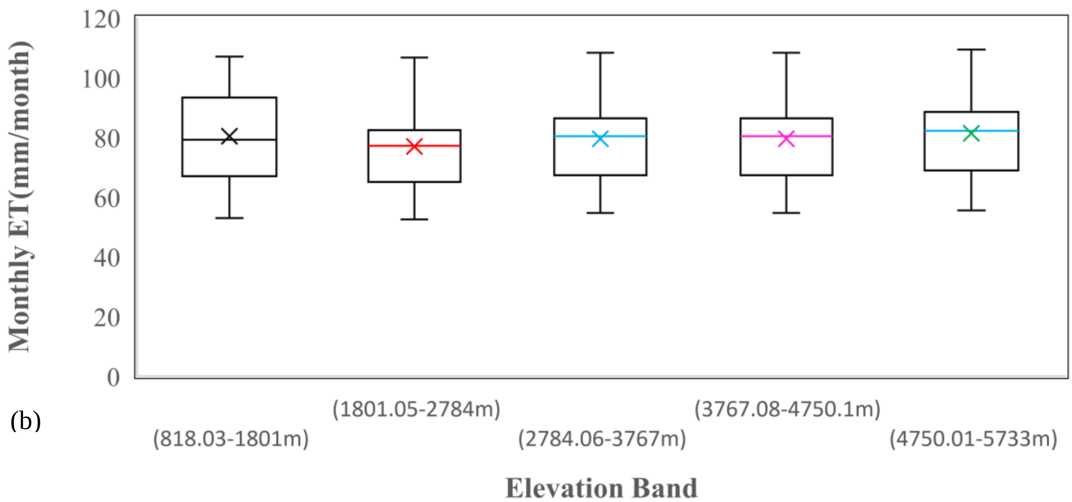
The study by [3] found that *ET* calculated by *PM* method yielded average daily ET of 2.6mm/day for 15 stations and monthly *ET* of 40-150 mm/month. Further it Hargreaves Equation was optimized for eight station with RMSE (0.586), MBE (-0.008) and R^2 also validated with observed data with RMSE (0.607), MBE (0.057), R^2(0.58). Although the current study could not validate the Turc's method, the results are in consistent with the previous study. The Turc method uses Temperature and solar radiation as the determining variables.

The Turc method uses temperature and solar radiation as the determining variables. It has shown that ET is increasing at given temperature and radiation with decrease in relative humidity below 50%. At higher relative humidity (RH>50) *ET* is mainly driven by radiation and temperature and RH does not have an impact.

A box plot was also used to dervive the information on the maximum, minimum, median, mean (marked by ×), outlier points, upper and lower quartile of monthly and daily *ET* of each elevation band as shown in *Figure 6*. The maximum *ET* rate at elevation (818.03-1801m) is in the month of November, which is 106.915 mm/day. At an elevation (818.03-1801m), Maximum ET rate in August month is 5.076 mm/day, Minimum ET in August month is 0.386 mm/day, Median of 2.476 mm/day, Mean value 2.633 mm/day, upper quartile is 3.277 mm/day and lower quartile with 1.942 mm/day.

(a)





(b)

Figure 6 (a) Daily ET Boxplot statistics (b) Monthly ET Boxplot statistics

Table 2 ET relation among the elevation band

Elevation Band	Avg ET	MAX ET rate(mm/day)	MIN ET rate(mm/day)	Mean ET rate(mm/day)
818.03 - 1801.5m	1309.77	-2.95011E-05	-1.01728E-06	-0.000114952
1801.5 - 2784.06m	2292.78			
1801.5 - 2784.06m	3767.08	3.25438E-05	2.03399E-06	3.45778E-05
2785.06 - 3767.08m	3276.07			
2785.06 - 3767.08m	5241.55	2.85127E-05	-2.03662E-06	9.97943E-05
3767.08- 4750.1m	3767.08			
3767.08- 4750.1m	3767.08	2.54248E-05	1.01699E-06	5.89857E-05
4750.1 - 5733m	5241.55			
818.03 - 1801.5m	1309.77	1.06822E-05	2.54337E-07	7.12145E-06
4750.1 - 5733m	5241.55			

Table 2 shows how daily *ET* varies with elevation change; the lowest elevation band (818.03-1801.5m) and highest elevation band (4750.1 - 5733m) shows that maximum *ET* increases at the 1.06822E-05 rate, the minimum *ET* increases by 2.54337E-07 rate and mean *ET* by 7.12145E-06 rate. Similarly *table 3* shows the monthly *ET* variation with elevation change.

Table 3 Change in monthly ET rate with Elevation band

Elevation Band	Avg ET	MAX ET rate(mm/month)	MIN ET rate(mm/month)	Mean ET rate(mm/day)
818.03 - 1801.5m	1309.77	-0.000763493	0.000313796	0.000322194
1801.5 - 2784.06m	2292.78			
818.03 - 1801.5m	1309.77	0.000702743	0.00154278	0.001783807
1801.5 - 2784.06m	2292.78			
1801.5 - 2784.06m	2292.78	0.000239443	0.0001829	0.000349608
3767.08- 4750.1m	3767.08			
3767.08- 4750.1m	3767.08	0.000732467	0.000570374	0.000671428
4750.1 - 5733m	5241.55			
818.03 - 1801.5m	1309.77	0.000705326	0.000502905	0.00069426
4750.1 - 5733m	5241.55			

IV. CONCLUSION

ET is the only component of water balance with the central role in hydrological, agricultural and drought events. This project estimated the daily *ET* of each elevation band for the year 2020 within the catchment of Kulong Chuu basin. The daily mean temperature and relative humidity obtained from NCHM and solar radiation from PADS has been interpolated with IDW technique for equally classified elevation band. The *ET* calculation was based on the Turc method (1961) that uses least parameters under humid conditions. It is based on the some easily available climatic data such as air temperature, solar radiation and relative humidity, and therefore, easy to apply whenever a full set of climatic data is not available. The Turc method uses Temperature and solar radiation as the determining variables. It was observed that the *ET* increased at given temperature and radiation with decreasing relative humidity below 50%. At higher relative humidity *ET* is mainly driven by radiation and temperature and relative humidity does not play a role anymore. At the lowest elevation (818.03-1801m) in Autumn season observed the highest *ET* of 280.141 mm/month and lowest *ET* of 175.186 mm/month in winter season. The regions at higher elevation (4750.01-5733m) observed highest *ET* of 275.793 mm/month in summer and lowest *ET* value 184.717 mm/day in winter. With the Annual *ET* of 395.633 mm/year in Kulong Chuu with Monthly *ET* ranging from 50-108 mm/month observed highest *ET* of 109.264 mm/month in the month of November at the highest elevation and 52.393 mm/month at the lowest elevation. It was observed *ET* rate at higher elevation (4750.01-5733m) was 2.35% higher compared to the lowest elevation (818.03-1801m). At the elevation (2784-5733m) monthly *ET* rates of (818.03-2784m) are comparable or even exceed those of lowlands. This implies that in even at the higher elevations considerable *ET* rates can be observed and that *ET* rates do not necessarily diminish with higher elevations.

ACKNOWLEDGEMENT

We would like to express our special thanks to Mr. Vasker Sharma for his guidance and continuous supervision as well as for providing required information about the project and also for his support in completing the project. Without his continuous guidance it would not have been possible for us to understand this project.

We would like to express our sincere gratitude to Jigme Namgyel Engineering College for providing us the opportunity to explore beyond the content. We have gained lots of knowledge while processing the project. We would like to acknowledge other staff that had helped us in solving doubts in our project. We would also like thank college library for helping us in some or any other way.

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